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DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

MATERIALS RESEARCH LABORATORY

MELBOURNE, VICTORIA

TECHNICAL NOTE

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HYDROCODE MODELLING OF THE MISAR ANTI-TANK MINE

David L. Smith and Ross J. Kummer

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ABSTRACT

Version 121 of the HULL code was used to predict the properties of the penetrator from the MISAR anti-tank mine. The code was run in pure Lagrange mode. Full HULL inputs are listed. The Lagrange rezoner for HULL was de-bugged, and a change deck to fix the rezoner is included.

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CONTENTS

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1. INTRODUCTION

The Australian Army is procuring anti-tank mines, known as SB-MV/1 Model DD, from the Italian manufacturer MISAR. The Australian Ordnance Council (AOC) was requested by Army to advise on the safety template for the mine under certain firing conditions. The Materials Research Laboratory (MRL) was in turn asked by the AOC [1] to provide data including estimates of the range, mass and velocity of fragments from the MISAR mine.

Part of the MRL study involved assessing the shape, velocity and travel of the main explosively formed copper penetrator. The time scale of the request precluded the conduct of a fully instrumented field trial to establish these parameters. Instead, the hydrodynamic computer code HULL was used to predict the collapse of the copper liner and the properties of the resulting penetrator. In this way an answer was achieved in two weeks.

2. A SIMPLIFIED MODEL OF THE MINE

A schematic view of the MISAR mine is given in Figure 1. The principal features to be noted are the truncated concave copper cone which forms the penetrator, and the annulus of high explosive (HE) behind it. The explosive used is Composition B, RDX/TNT 60/40. Initiation is by means of a centrally initiated primary booster pellet of Tetryl, and an annular secondary booster of Composition A3 (RDX/Wax 91/9). Fuzing and sensing components are forward of the copper liner and are removed before detonation of the main charge by a propellant expelling charge. The entire mine assembly is encased in a plastic body.

For modelling purposes, the mine was approximated by only its copper liner and high explosive charge. The confining effect of the plastic body was assumed to be small, and was ignored. Initiation was approximated by using a cylindrical initiation

front (a line in two dimensions) to represent the initiator, which was not modelled directly. The mine's geometry was approximated by digitisation of the liner and HE charge from schematic diagrams. The result is shown in Figure 2. The masses from the digitised model were 858 g of copper and 2468 g of Composition B.

3. MODELLING WITH THE HULL CODE

Calculations were performed with version 121 of the HULL code [2], in pure Lagrange mode. The material models used for copper and Composition B were as provided in the HULL system. Calculations were in two dimensions with rotational symmetry. All calculations were performed on the MRL Vax 8700 computer. 400 nodes were used to describe the copper liner, and 2100 nodes to describe the explosive. The explosive chosen from HULL was US Composition B, with a density of 1720 kg/m^3 and a velocity of detonation 7.98 km/s. The full HULL mesh generator (KEEL) input is listed as part of Appendix A. Figure 3 is a plot of the resultant HULL mesh at time zero.

Cells at the edges of the metal liner and the explosive had to be dropped during the calculation, because of extreme distortion of the mesh. This is normal for a Lagrange calculation of this type, and for the metal liner, suggests that minor fractures would occur at the edges. The explosive was entirely dropped from the calculation at 30 microseconds of problem time, because of the normal difficulties with highly expanded Lagrange meshes. The overall effect of these approximations during the course of the calculation will be small. At the time of dropping all the HE, pressures in the explosive cells were almost all below 10 kbar, ie about 3% of the (peak) C-J pressure. Wilkins [3] asserts that for most explosive-metal simulations the explosive itself becomes fairly unimportant below 10 kbar. The dropping of the metal and HE edge cells will lead to error in the total mass available for formation of the projectile. However as the metal and HE in the affected areas were dropped simultaneously, the effect should be small in *proportional* terms, ie the effect on final projectile velocity should be small, even though the mass will be wrong. It should also be noted that some of the metal cells dropped from the calculation will correspond to real-life fractures.

It is normal for Lagrangian explosive - metal calculations of this sort to be sensitive to viscosity terms in the code. In the present calculation, the hourglass, or bowtie, viscosity required careful choice. Experimentation showed that a value of 70,000 for the HULL variable XLBOW worked best with the copper and HE both present. This value was increased to 100,000 later in the calculation after the HE had been dropped. Full HULL cycler inputs are included in Appendix A. Plots of the entire HULL calculation are presented in Figures 4 to 16. Note that all figures are to the same scale; the liner appears bigger in later plots because the outer elements have moved in towards the axis of symmetry. Elements of equal projected area have a (rotated) mass content proportional to the square of their distance from the axis of symmetry.

At 47.5 microseconds, as shown in Figure 8, the copper liner was folding in on itself, and causing problems with the calculation. The solution was to use the Lagrange rezoner in HULL to produce a better behaved mesh. Unfortunately, the rezoner supplied

with version 121 of HULL had several bugs which needed to be fixed before it could be used. Appendix B lists the HULL change deck used to fix the rezoner.

Once the rezoner was working, the rezone was achieved in three passes, as illustrated in Figures 9 to 11. The first rezone "transformed" the zone of 9 elements nearest to the axis, swapping the x and y lines back as this zone had turned through 90 degrees. The second rezone joined across the area of the fold itself. This introduced some artificial inaccuracy, but the total accuracy loss as shown by the energy and momentum balances within the rezoner was less than 2 percent. The third rezone was a simple automatic rezone of the entire copper region, and this produced a well behaved mesh, as shown in Figure 11. The input decks for the three rezones are reproduced in Appendix A.

Further rezones were tried later to accommodate the problem of stretching metal at the front of the liner, on the axis. This proved too difficult, and the offending cells were dropped at 59 microseconds. This metal might well detach from the main liner mass in reality. From this point, the calculation was run without interference to 300 microseconds, at which time the projectile had almost entirely stabilised in both shape and velocity.

4. RESULTS

The HULL calculations suggest that the MISAR mine will generate a long, forward folding fragment. The fragment achieves a stable shape within 300 microseconds, and in fact changes very little after 150 microseconds. The final length of the fragment is 200 mm, and diameter 30 mm. The predicted velocity is 1.73 km/s. These predictions seem reasonable, and would make for an effective penetrator. It should also be noted that the formation of the penetrator is achieved within about 300 mm of the front face of the liner.

It should be emphasised that the HULL calculations were made without any supporting experimentation. Although the results seem reasonable, it may be that experimental results would suggest changes to viscosity factors in the calculations, and produce some change to the final fragment shape. Also because highly deformed zones had to be dropped during the calculation, the final projectile mass was lower than it would be in reality (750 g out of 960 g). Despite these limitations, it is likely that the velocity prediction is reasonably accurate, as the energy deposition will not be very sensitive to refinements to artificial viscosities or material models.

5. CONCLUSIONS

The Lagrange section of the HULL code [2] proved to be useful for quickly predicting the liner collapse and penetrator formation for the MISAR mine. The Lagrange rezoner for HULL was de-bugged, and is now a useful tool for this type of calculation.

This is the first attempt at MRL to use a modern version of HULL for calculating self-forging fragment (SFF) or explosively formed projectile (EFP) formation. The success of this calculation will enable further work on SFF's to be done in the near future.

6. REFERENCES

1. MRL File 34/13/4, Folio 15.

2. Matuska, D.A. and Osborne, J.J. HULL Documentation, Volume 2 "HULL Users Manual", Orlando Technology Inc., Florida, 1985.

3. Wilkins, M.L. Private communication.

First LREZ input (rezoner)

```
LREZ PROB=3856.0
REGION=1
NXI=53 NYJ=4
NT=FREE NX=1,53 NY=1,1
NT=FREE NX=1,53 NY=4,4
NT=FREE NX=1,1 NY=2,3
NT=FREE NX=53,53 NY=2,3
REZONE AREA NX=1,4 NY=1,4
OLD NX=4,7 NY=1,4
MAT=1
TYPE=1
NY=1 OLD NX=6 NY=1
    X=0.1 Y=9.191
    X=0.2 Y=9.089
    OLD NX=7 NY=1
NY=4 OLD NX=4 NY=1
    OLD NX=4 NY=2
    OLD NX=4 NY=3
    OLD NX=7 NY=4
NX=1 X=0.0 Y=10.3
    OLD NX=5 NY=1
REZONE AREA NX=5,53 NY=1,4
OLD NX=8,56 NY=1,4
NO CHANGE
```

Second LREZ input

```
LREZ PROB=3856.0
REGION=1
NXI=53 NYJ=4
NT=FREE NX=1,53 NY=1,1
NT=FREE NX=1,53 NY=4,4
NT=FREE NX=1,1 NY=2,3
NT=FREE NX=53,53 NY=2,3
REZONE AREA NX=1,2 NY=1,4
OLD NX=1,2 NY=1,4
NO CHANGE
REZONE AREA NX=3,13 NY=1,4
OLD NX=3,13 NY=1,4
MAT=1
TYPE=1
NY=4 OLD NX=3 NY=4
    X=0.5469100    Y=12.07183
    X=0.5872200    Y=12.03886
    X=0.6275300    Y=12.00589
    X=0.6678400    Y=11.97292
    X=0.7081500    Y=11.93995
    X=0.7484600    Y=11.90698
    X=0.7887700    Y=11.87401
    X=0.8290800    Y=11.84104
    X=0.8693900    Y=11.80807
    OLD NX=13 NY=4
```

```
CHANGE NX=   3 NY=  1  X=  0.2000 Y=   9.0890
CHANGE NX=   4 NY=  1  X=  0.3015 Y=   8.9865
CHANGE NX=   5 NY=  1  X=  0.6754 Y=   9.1606
CHANGE NX=   6 NY=  1  X=  0.8974 Y=   9.4186
CHANGE NX=   7 NY=  1  X=  1.0606 Y=   9.6741
CHANGE NX=   8 NY=  1  X=  1.1904 Y=   9.9112
CHANGE NX=   9 NY=  1  X=  1.2871 Y=  10.1543
CHANGE NX=  10 NY=  1  X=  1.3743 Y=  10.3692
CHANGE NX=  11 NY=  1  X=  1.4530 Y=  10.5547
CHANGE NX=  12 NY=  1  X=  1.5199 Y=  10.7297
CHANGE NX=  13 NY=  1  X=  1.5887 Y=  10.8900
CHANGE NX=   3 NY=  2  X=  0.3390 Y=   9.9006
CHANGE NX=   4 NY=  2  X=  0.5039 Y=   9.7428
CHANGE NX=   5 NY=  2  X=  0.6706 Y=   9.5634
CHANGE NX=   6 NY=  2  X=  0.8246 Y=   9.7323
CHANGE NX=   7 NY=  2  X=  0.9600 Y=   9.9431
CHANGE NX=   8 NY=  2  X=  1.0632 Y=  10.1671
CHANGE NX=   9 NY=  2  X=  1.1379 Y=  10.3900
CHANGE NX=  10 NY=  2  X=  1.1983 Y=  10.5940
CHANGE NX=  11 NY=  2  X=  1.2565 Y=  10.7758
CHANGE NX=  12 NY=  2  X=  1.3145 Y=  10.9451
CHANGE NX=  13 NY=  2  X=  1.3806 Y=  11.1014
CHANGE NX=   3 NY=  3  X=  0.3393 Y=  10.7906
CHANGE NX=   4 NY=  3  X=  0.5026 Y=  10.5427
CHANGE NX=   5 NY=  3  X=  0.6483 Y=  10.0851
CHANGE NX=   6 NY=  3  X=  0.7852 Y=  10.2089
CHANGE NX=   7 NY=  3  X=  0.8712 Y=  10.4081
CHANGE NX=   8 NY=  3  X=  0.9208 Y=  10.6175
CHANGE NX=   9 NY=  3  X=  0.9531 Y=  10.8142
CHANGE NX=  10 NY=  3  X=  0.9888 Y=  10.9840
CHANGE NX=  11 NY=  3  X=  1.0356 Y=  11.1336
CHANGE NX=  12 NY=  3  X=  1.0947 Y=  11.2727
CHANGE NX=  13 NY=  3  X=  1.1670 Y=  11.4009
REZONE AREA NX=14,53 NY=1,4
OLD NX=14,53 NY=1,4
MAT=1
TYPE=1
NX=14 OLD NX=14 NY=2
    OLD NX=14 NY=3
```

Third LREZ input

```
LREZ PROB=3856.0
REGION=1
NXI=53 NYJ=4
NT=FREE NX=1,53 NY=1,1
NT=FREE NX=1,53 NY=4,4
NT=FREE NX=1,1 NY=2,3
NT=FREE NX=53,53 NY=2,3
REZONE AREA NX=1,53 NY=1,4
OLD NX=1,53 NY=1,4
MAT=1
TYPE=1
```

Second HULL input (47.5 to 57.5 microseconds)
Note change in XLBOW from 70,000 to 100,000

```
HULL LAGRANGE PROB=3856.0
CYCLE=99999
XKX=0.4
DTMIN=1.E-11
XLBOW=100000.
DMPINT=2.5E-06
PTSTOP=57.5E-06
```

Third HULL input (57.5 to 200 microseconds)

```
HULL LAGRANGE PROB=3856.0
CYCLE 99999
XKX=0.4
XLBOW=100000.
DTMIN=1.E-11
DMPINT=10.0E-06
PTSTOP=300.0E-06
TDROP=59.0E-06 REGION 1 NX=1,11 NY=3,4
NT=VOID NX=1,10 NY=4,4
NT=FREE NX=2,11 NY=3,3
```

PULL input (plot mesh)

```
PULL PROB=3856.0
REF
XMIN=0 DX=2
YMIN=0 DY=2
YMOVE=1
LMESH
```

APPENDIX B - HULL Change Deck to fix Lagrange Rezoner

```
SAIL UPDATE NOLIST
*I 50123
=   SET PDISK WHEN LAGRANGE REZONE IN USE ... SMITH AND KUMMMER 1988
*NDEFN PDISK=0
*D 98311
C     FIX THE RESTART BUG FOR DROPPED ELEMENTS. DAVID SMITH 5/9/88.
      IF (MAT.LE.0) GOTO 3000
*I 182478
=     PATCH IN MORE INCLUDES .... SMITH AND KUMMER SEPT 1988
*INCLUDE SLTCOM LTIME
*INCLUDE LBCOM
*D 182584
C     FIX POINTER BUG, AND MAKE SURE NOT LOOKING FOR MASTER IN LAST
C     REGION.   DAVID SMITH AND ROSS KUMMER 31-AUG-1988
      IF(N.EQ.NLREG)GOTO 50
      NBLEND = BOUNDS(N,1)
*D 182602
=     PROVIDE THE MISSING LOOP  ... SMITH AND KUMMER SEPT 1988
      DO 770 NR=NSTART,NLREG
*I 182616
=     PROVIDE SOME MISSING STATEMENTS  ... SMITH AND KUMMER SEPT 1988
65    CONTINUE
770   CONTINUE
      ENDIF
*D 182707
C     FIX LOOP POINTER BUG.   DAVID SMITH 31-AUG-1988
80    HL(LSTART + L) = HL(LOLD + L)
*I 182716
=     INCLUDE MISSING COMMON   SMITH AND KUMMER SEPT 1988
*INCLUDE LBCOM LSLIDE
*I 182717
=     INCLUDE MISSING COMMON   SMITH AND KUMMER SEPT 1988
*INCLUDE SLTCOM LTIME
*D 182752,182755
=     FIX INNER LOOP WITH SAME COUNTER AS SURROUNDING OUTER LOOP
=     DAVID SMITH AND ROSS KUMMER SEPT 1988
      DO 30 III=1,4
      NODE(III)=NOLD+(NODE(III)-NFIRST(NRREG))*NODVAR
      XN(III)=HN(NODE(III)+NX)
      YN(III)=HN(NODE(III)+NY)
*D 182785
=     FIX TYPO IN 121  X() TO XN() ... SMITH AND KUMMER 1988
     SH=(XN(2)-XN(1))*(YN(3)-YN(1))-(YN(2)-YN(1))*(XN(3)-XN(1))
*I 182940
=     INCLUDE MISSING COMMON ... SMITH AND KUMMER SEPT 1988
*INCLUDE SLTCOM LTIME
*INCLUDE LBCOM
*I 183041
=     SUPPLY THE MISSING STATEMENT ... SMITH AND KUMMER SEPT 1988
800   CONTINUE
```

```
*D 183681
=      UNNECESSARY *ENDPROC DELETED ... SMITH AND KUMMER SEPT 1988
*D 183775
=      UNNECESSARY *ENDPROC DELETED ... SMITH AND KUMMER SEPT 1988
*D 183776
=     USE ARGUMENT THAT IS NOT IN A COMMON (ISLN2) ... D SMITH 1988

      SUBROUTINE SLMAST (NODE,MAST1,MAST2,ISLN2,ISEND)
*D 183788
      IS=ISLN2
*D 183845
=      UNNECESSARY *ENDPROC DELETED ... SMITH AND KUMMER SEPT 1988
*I 183849
=      INCLUDE MISSING COMMON ... SMITH AND KUMMER SEPT 1988
*INCLUDE LBCOM LSLIDE
*I 185109
=      INCLUDE MISSING PROC ... SMITH AND KUMMER SEPT 1988
*INCLUDE WRSTAT LTIME
```

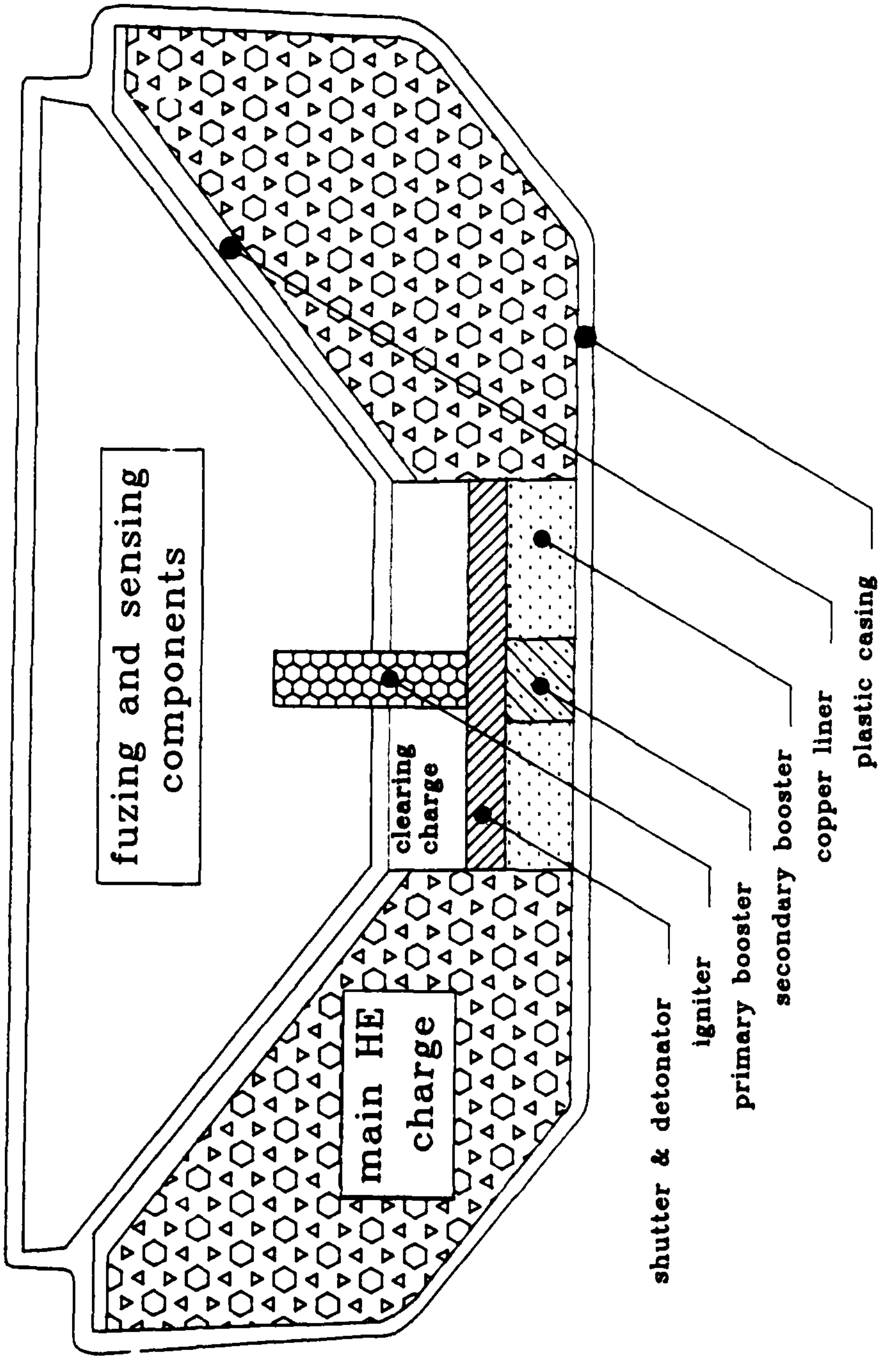

FIGURE 1 A schematic diagram of the MISAR mine

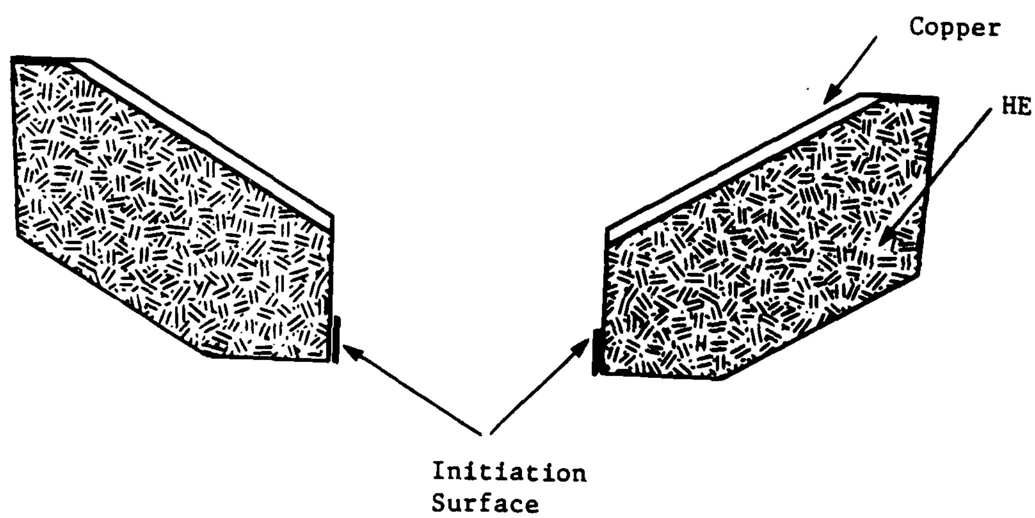

FIGURE 2 Simplified model of the mine from digitisation

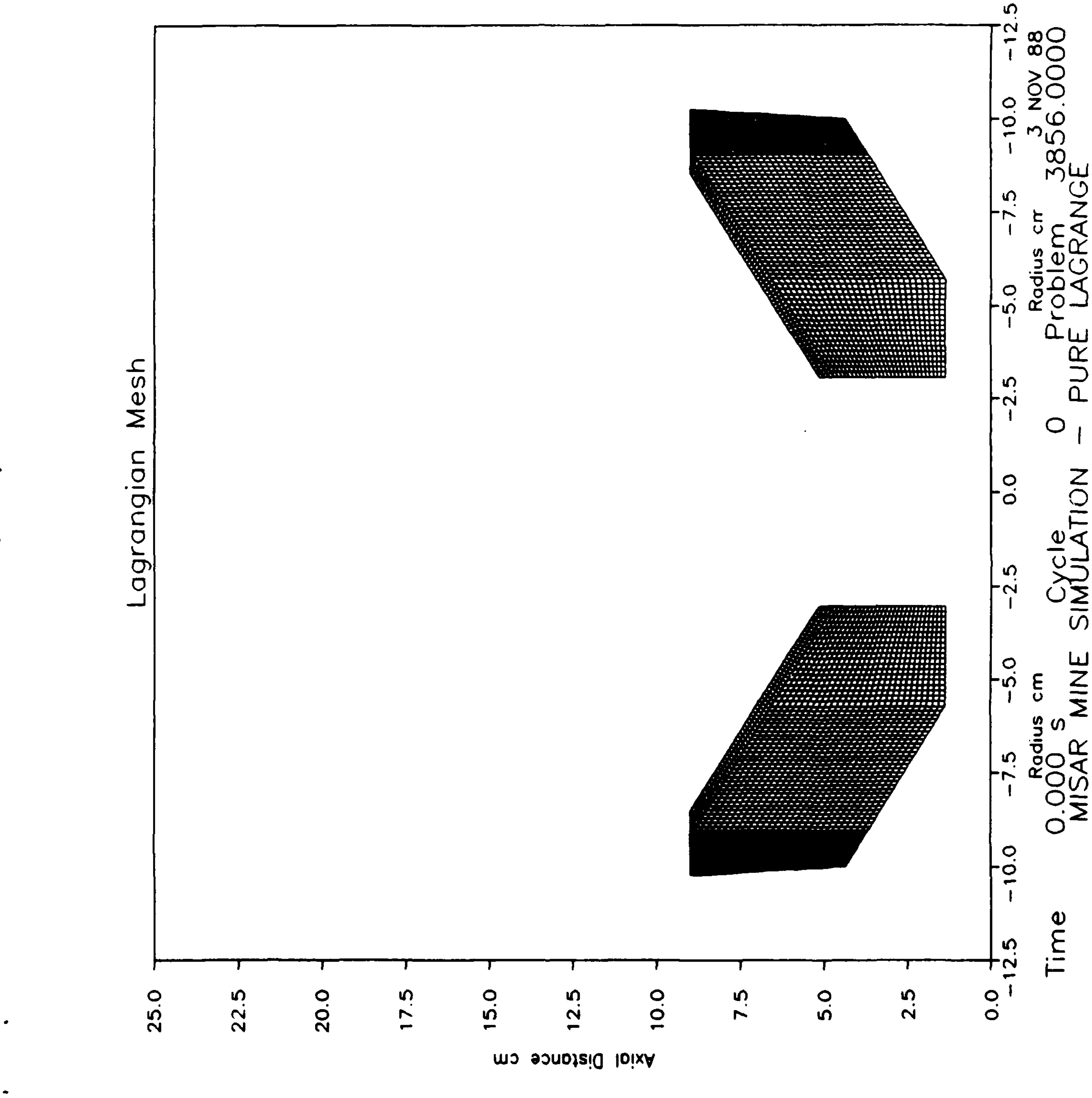

FIGURE 3 **HULL calculational mesh at time zero**

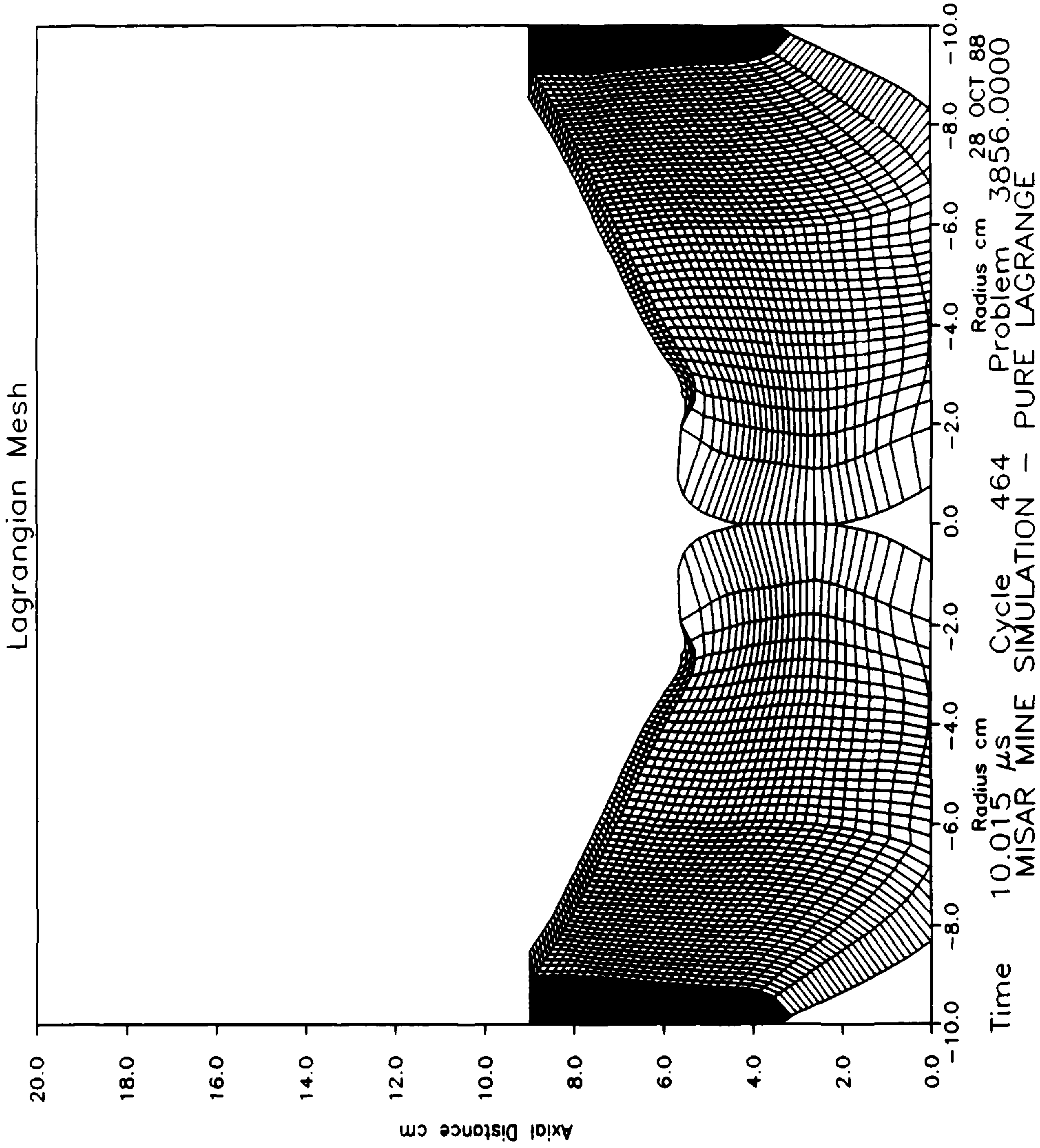

FIGURE 4 Plot of HULL calculations at 10 microseconds

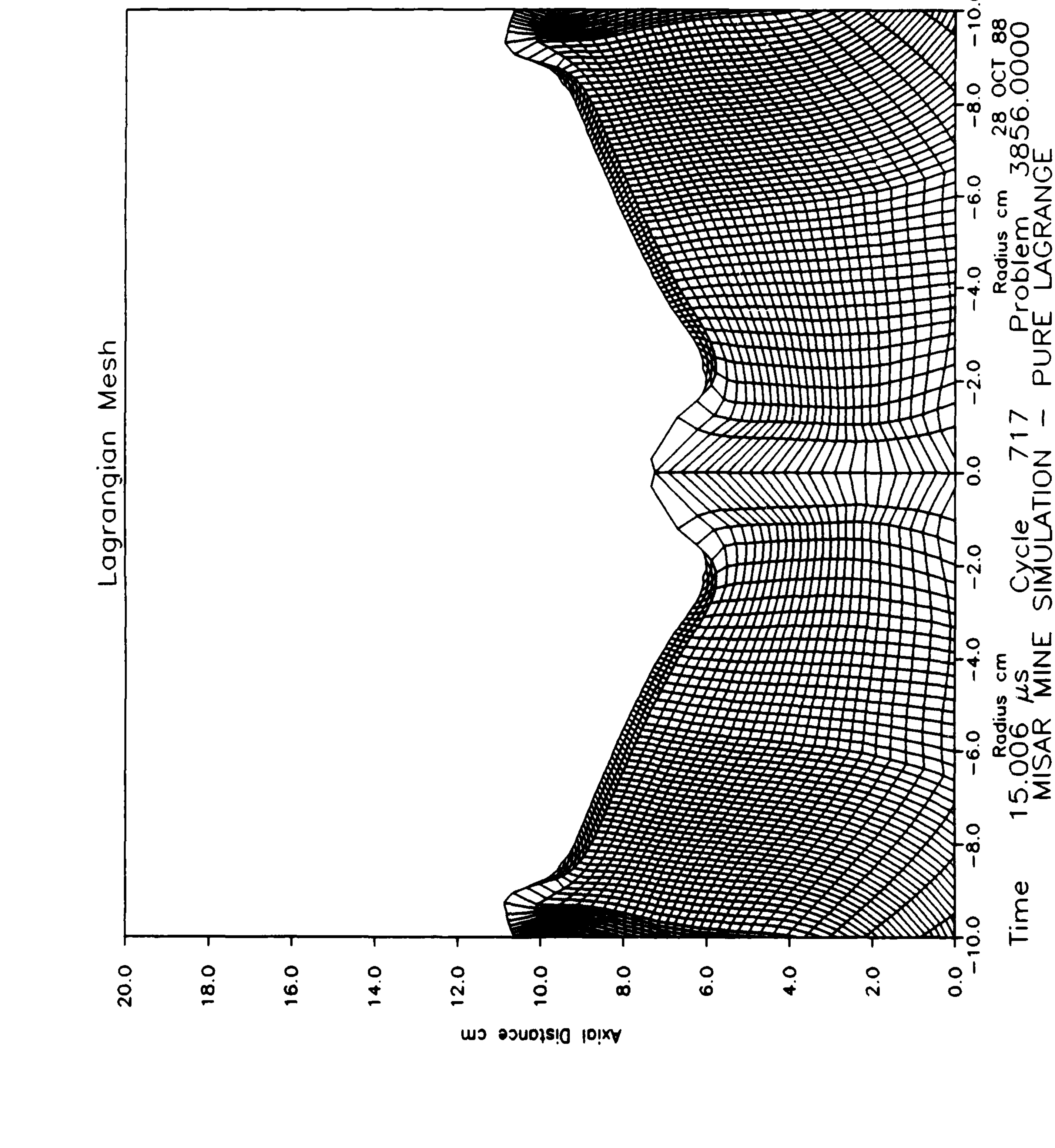

FIGURE 5 Plot of HULL calculation at 15 microseconds

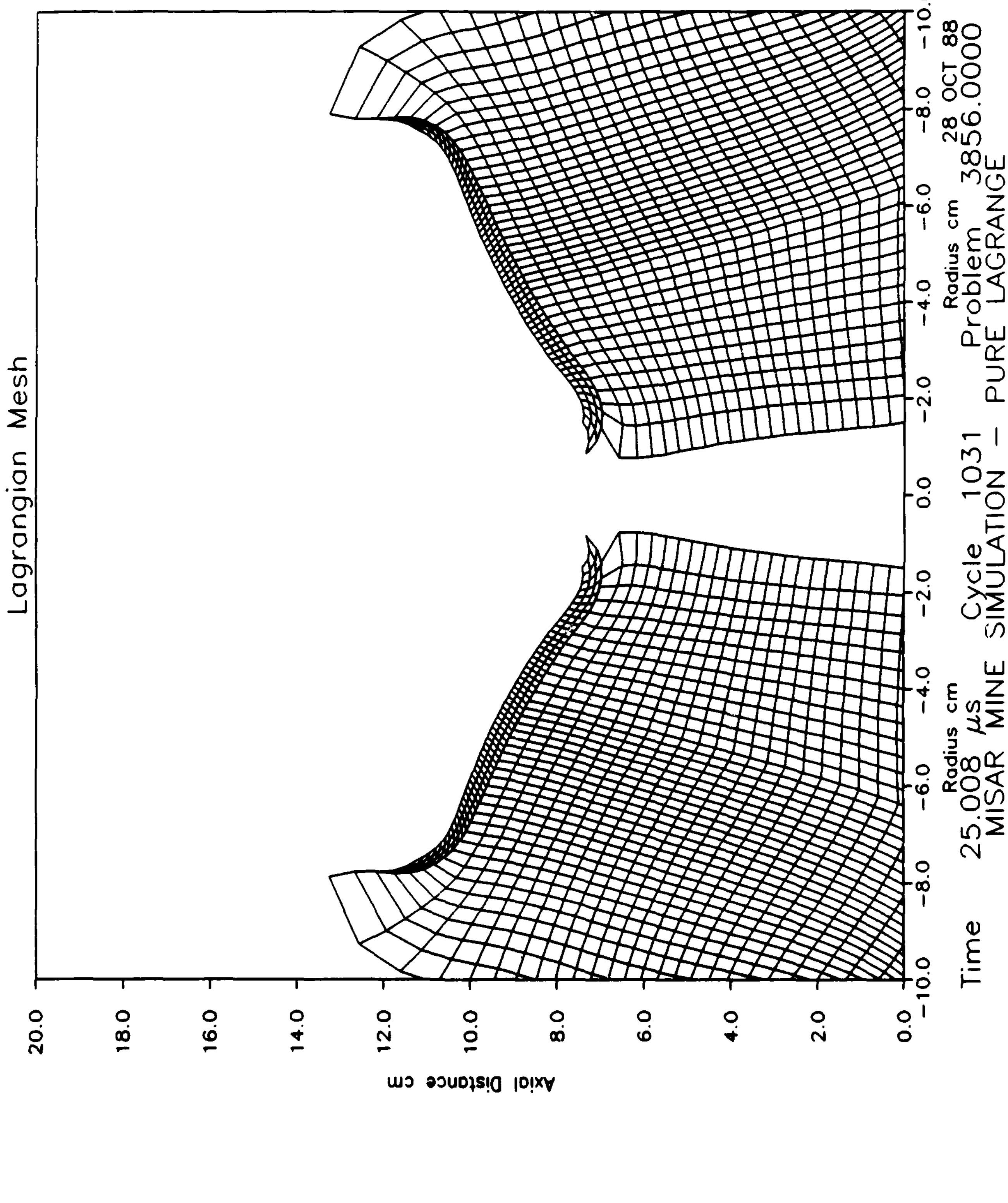

FIGURE 6 Plot of HULL calculation at 25 microseconds

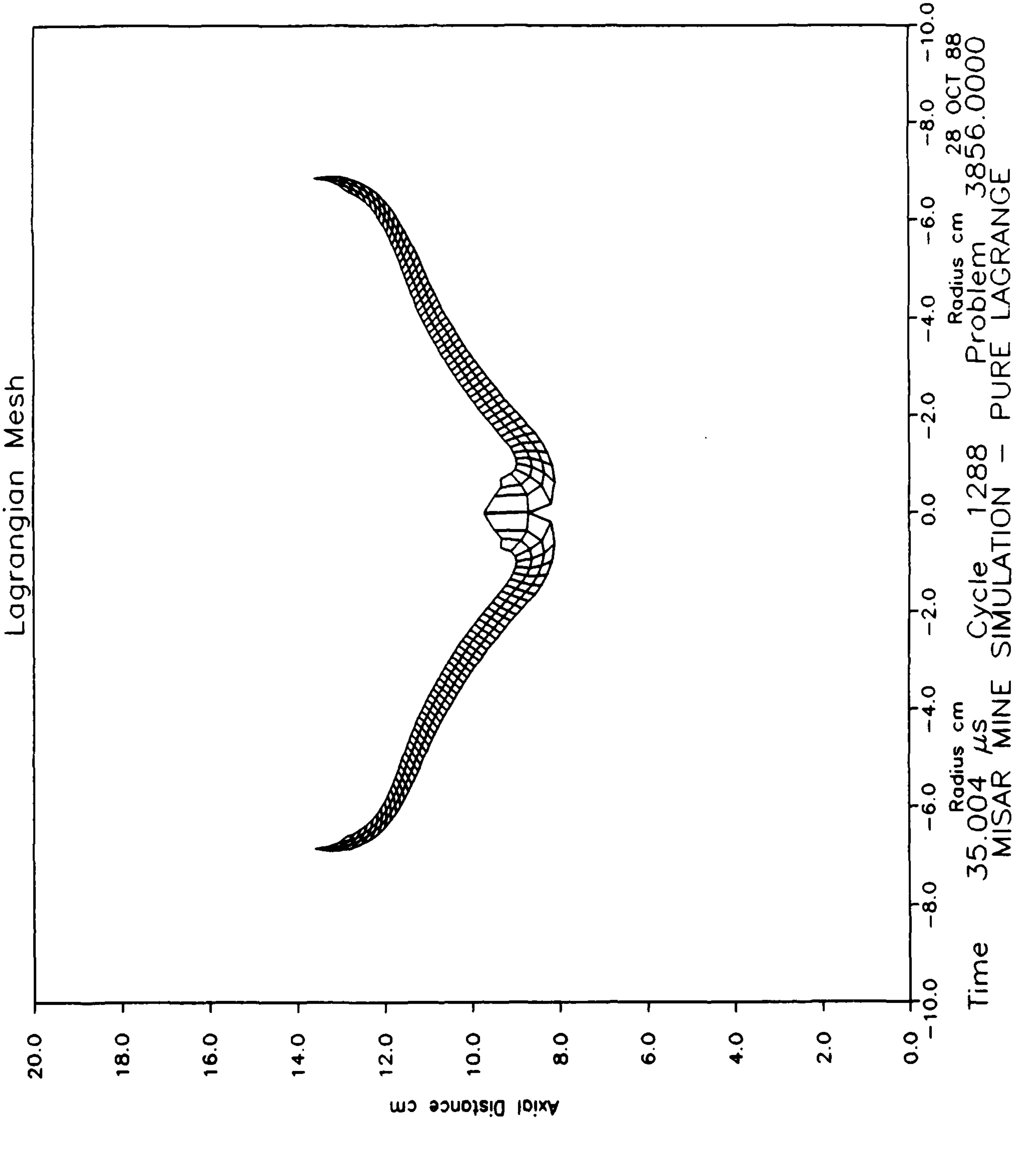

FIGURE 7 **Plot of HULL calculation at 35 microseconds**

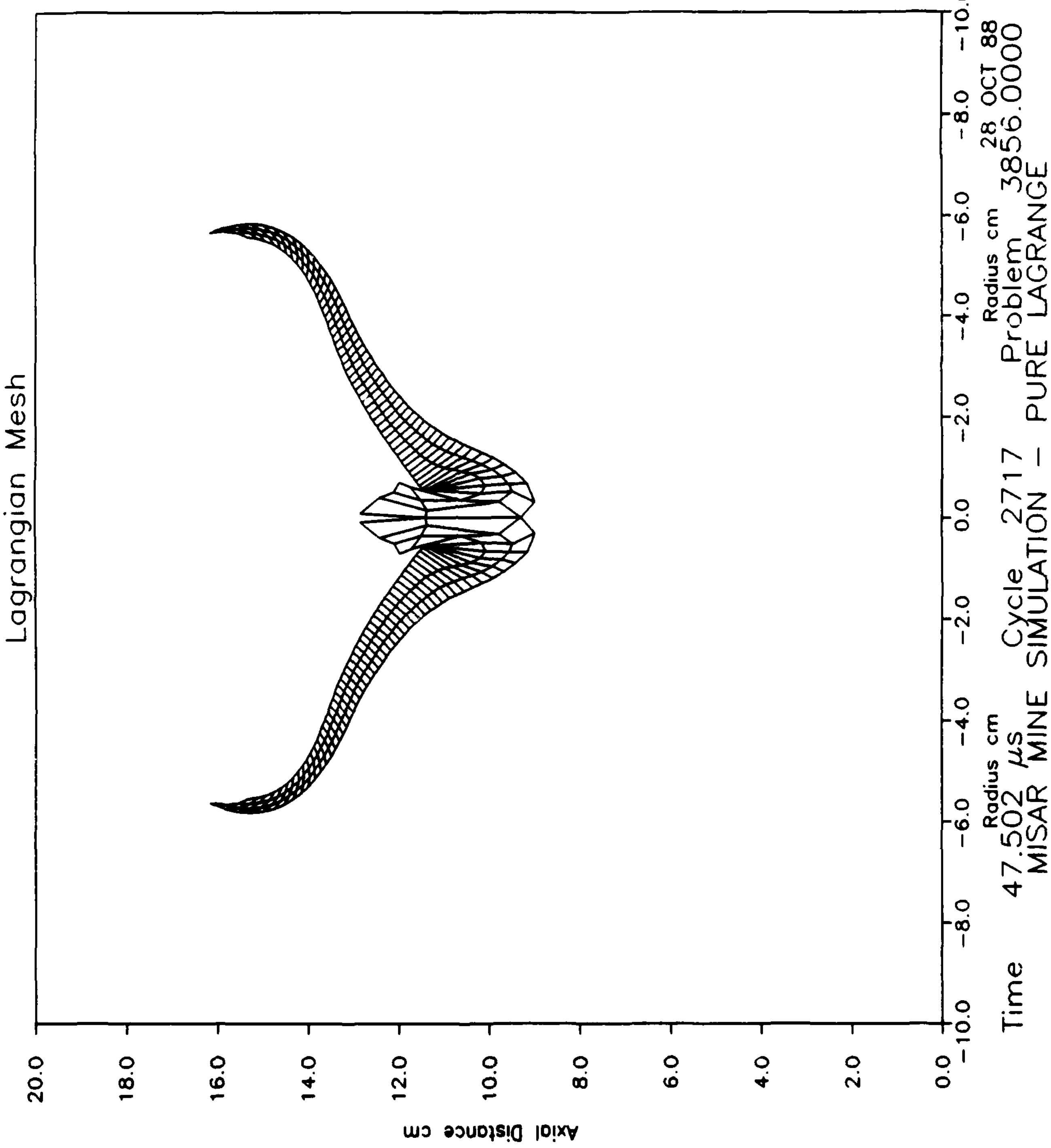

FIGURE 8 Plot of HULL calculation at 47.5 microseconds

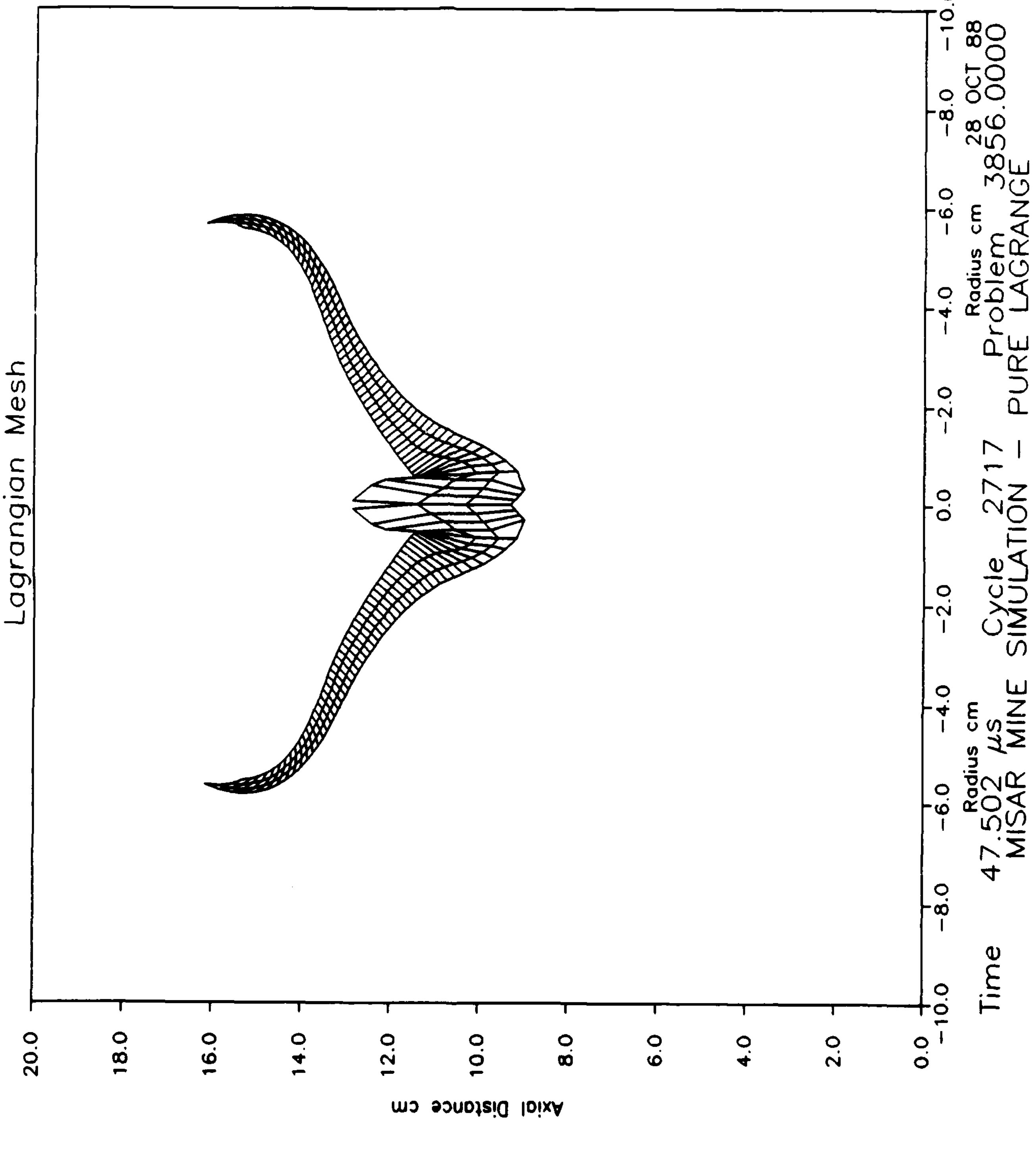

FIGURE 9 **Plot of HULL calculation at 47.5 microseconds after first rezone**

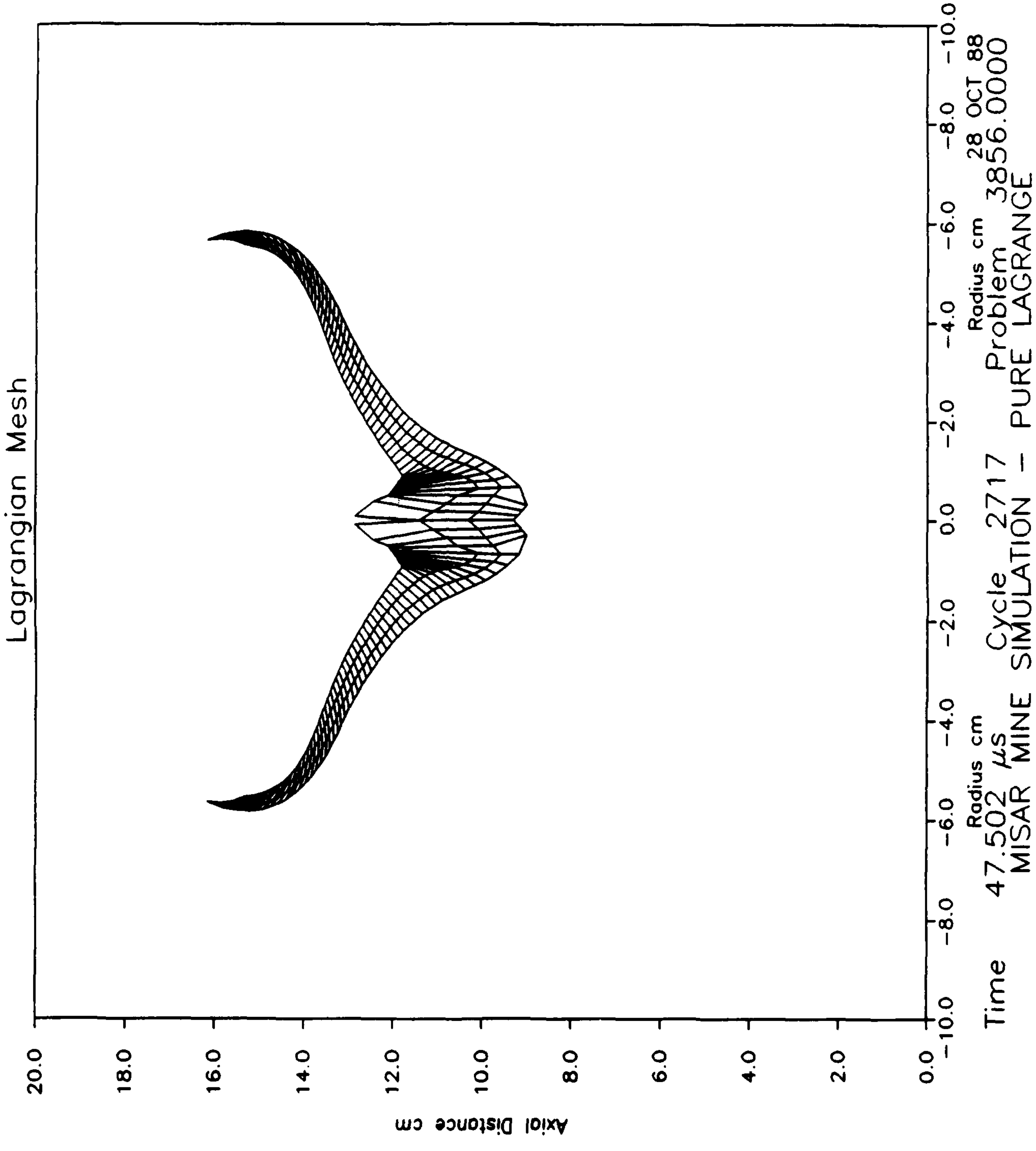

FIGURE 10 Plot of HULL calculation at 47.5 microseconds after second rezone

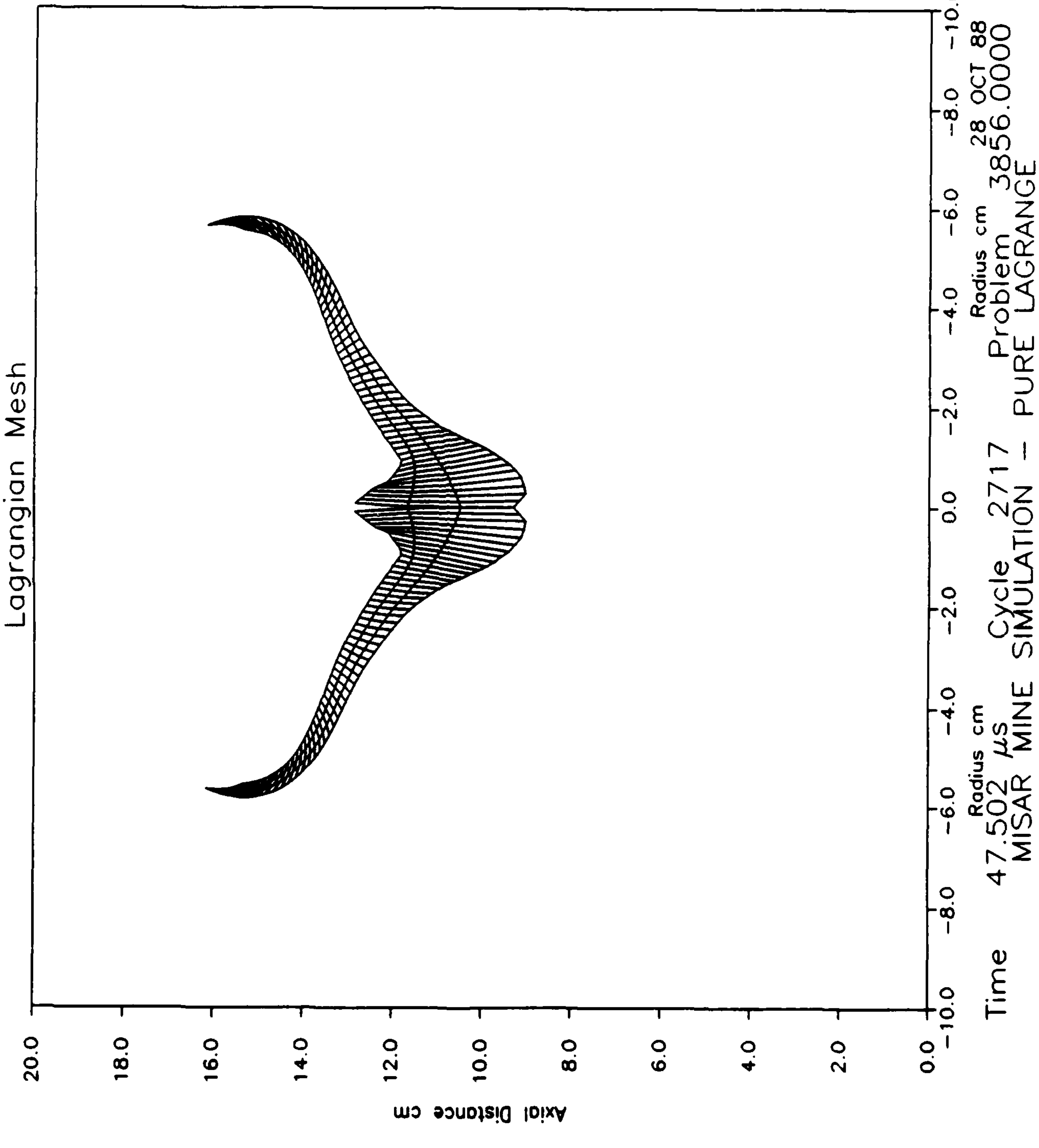

FIGURE 11 Plot of HULL calculation at 47.5 microseconds after third rezone

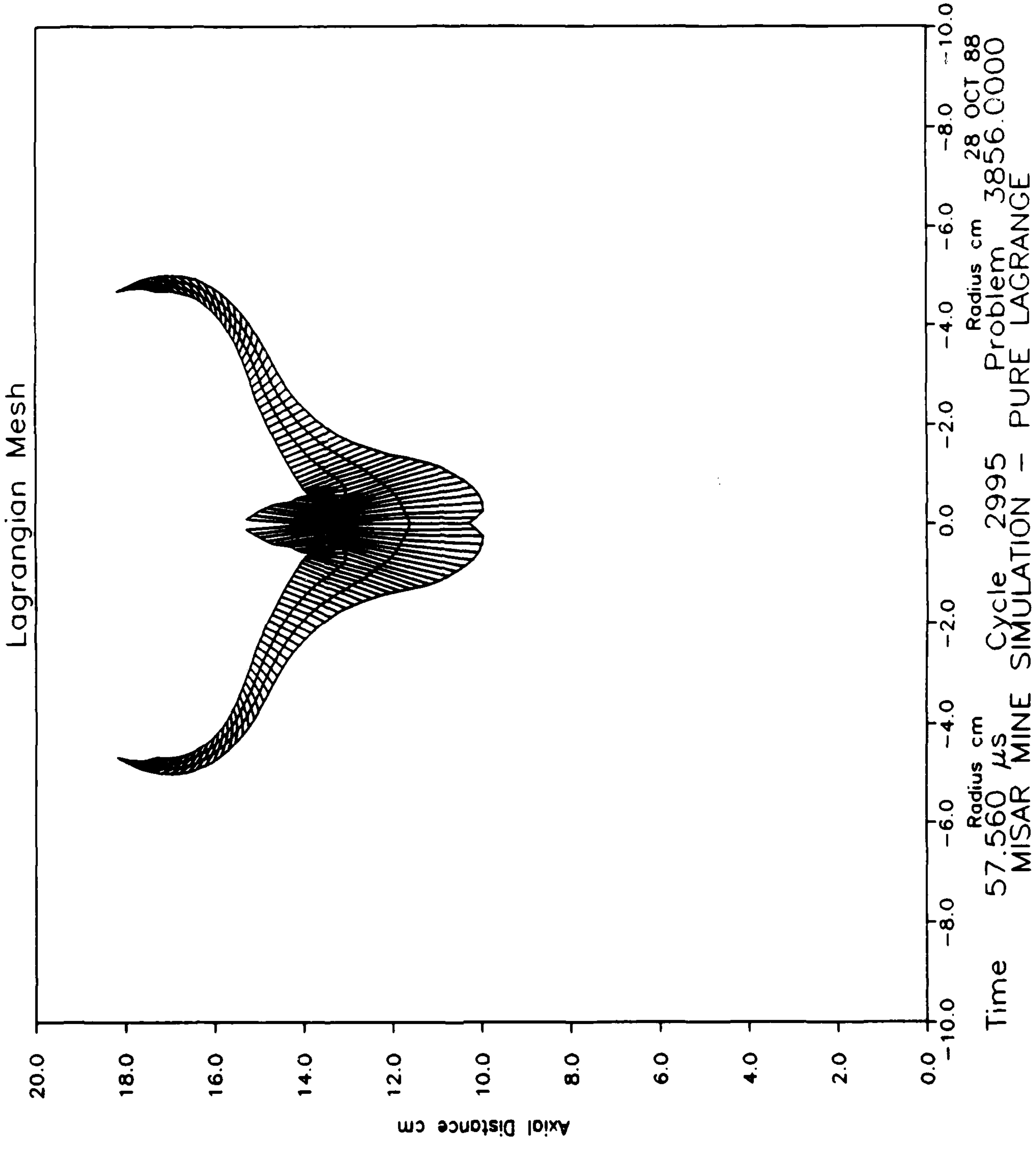

FIGURE 12 Plot of HULL calculation at 57.5 microseconds

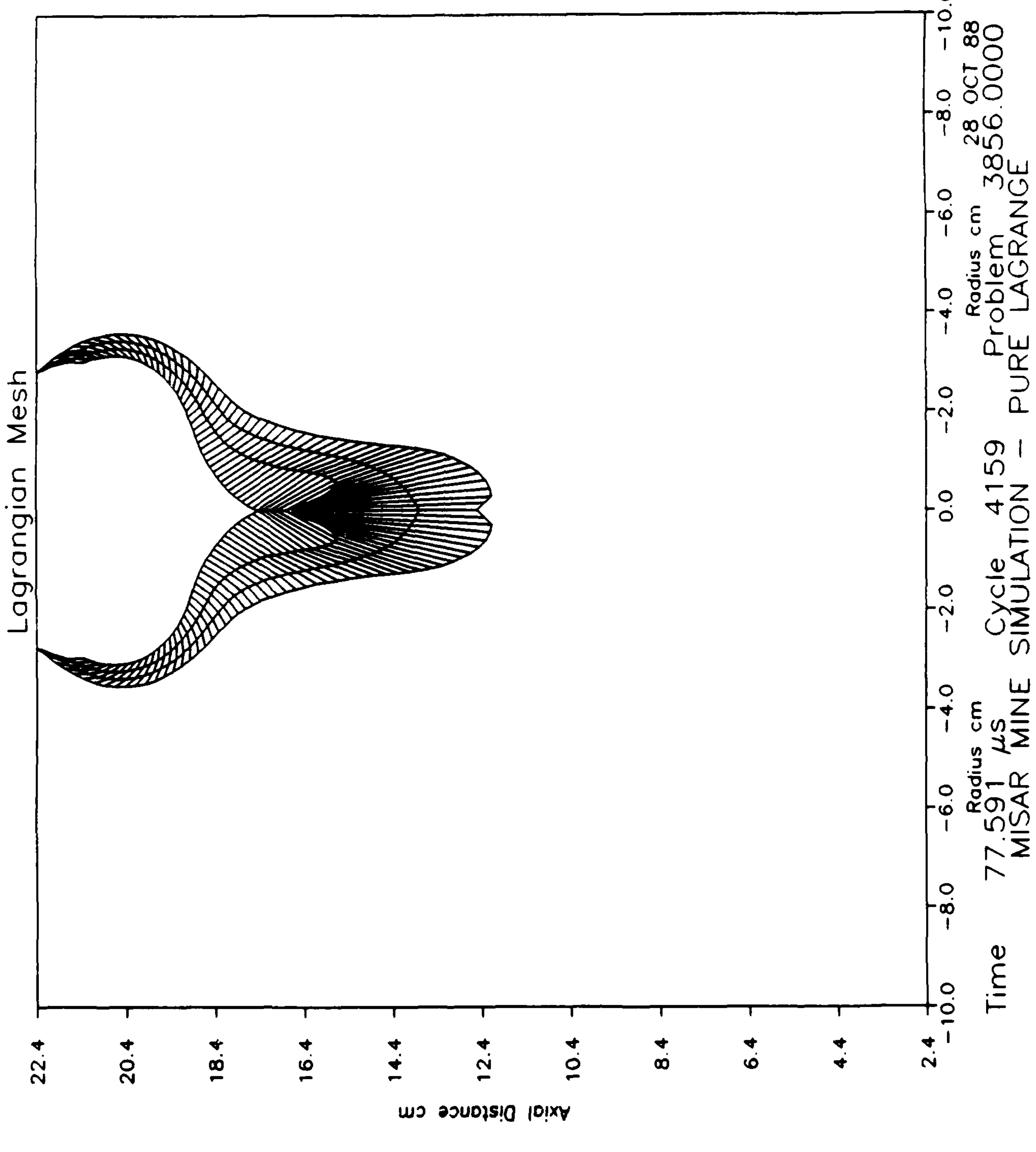

FIGURE 13 Plot of HULL calculation at 77.6 microseconds

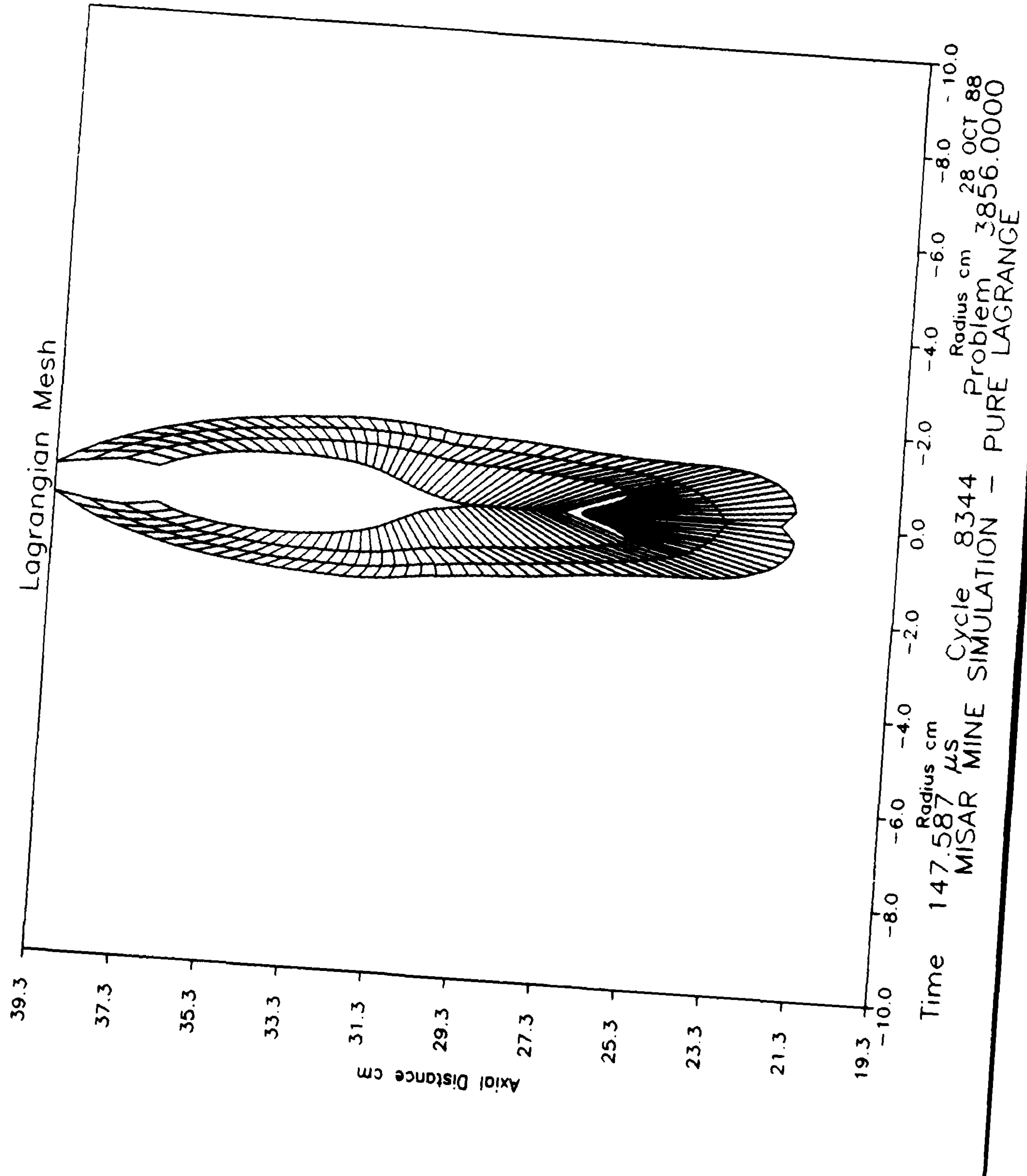

FIGURE 14 Plot of HULL calculation at 147.6 microseconds

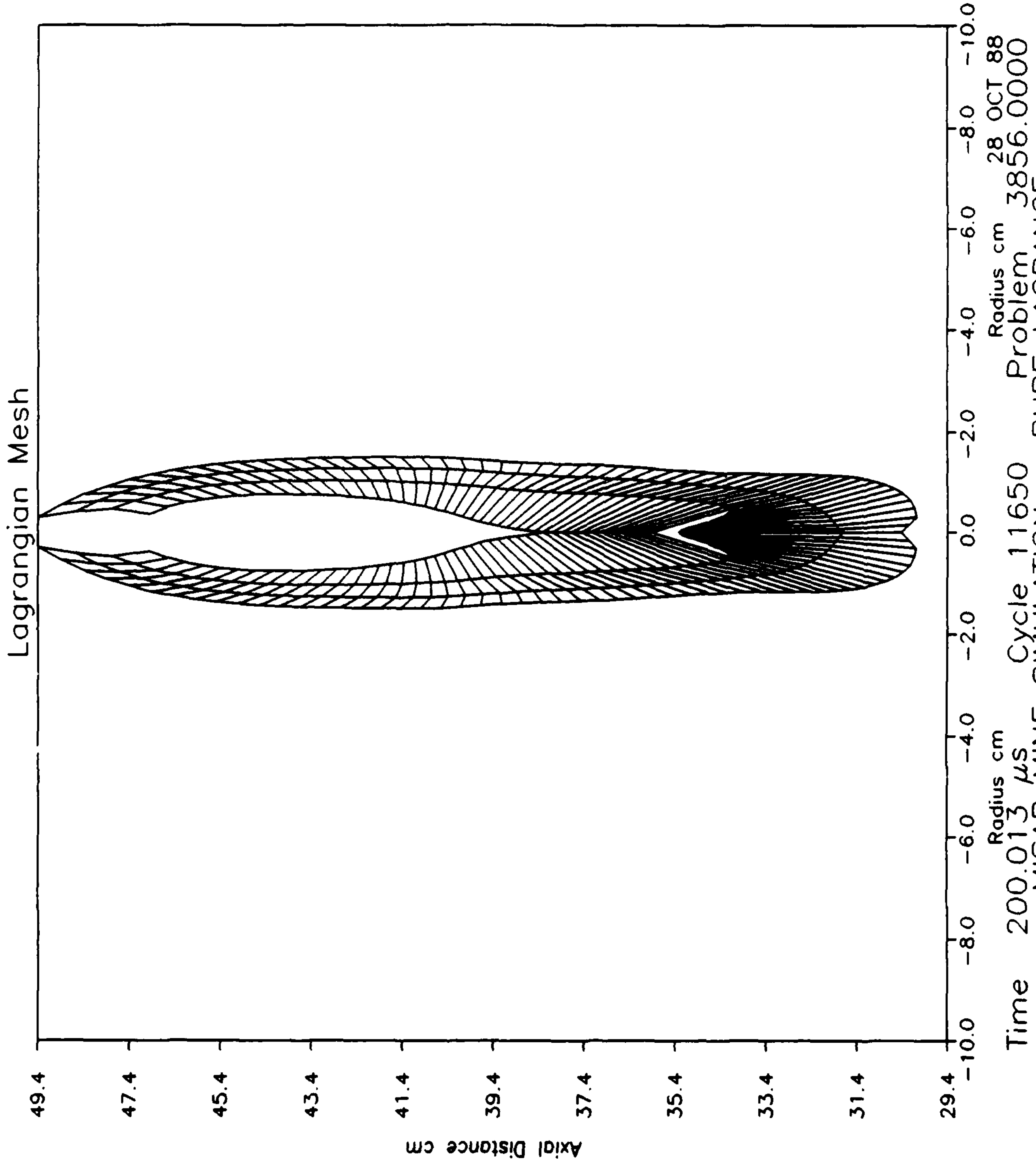

FIGURE 15 Plot of HULL calculation at 200 microseconds

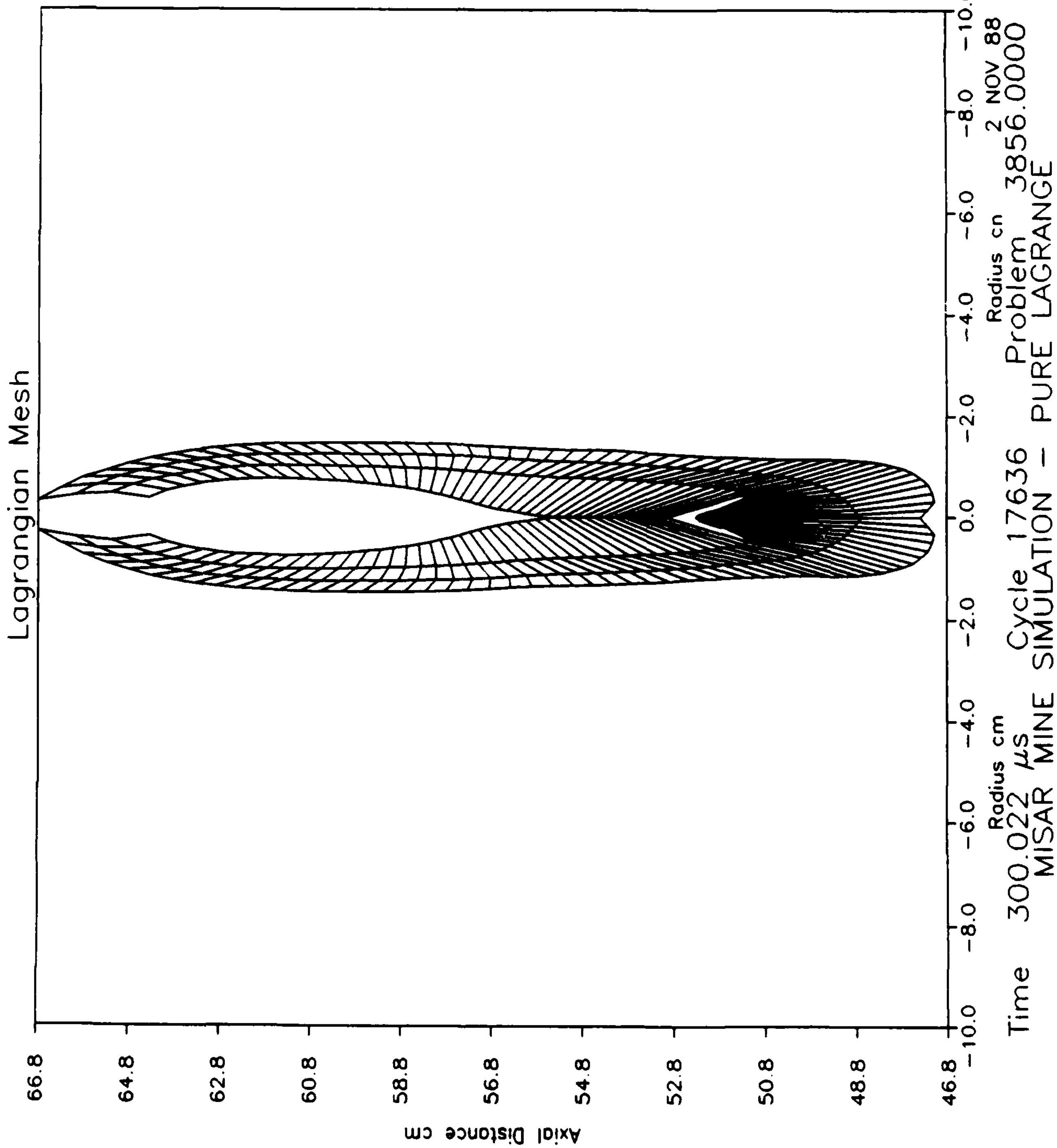

FIGURE 16 **Plot of HUll calculation at 300 microseconds**

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